Integrated Model for Production-Distribution Coordination in an Industrial Gases Supply-chain

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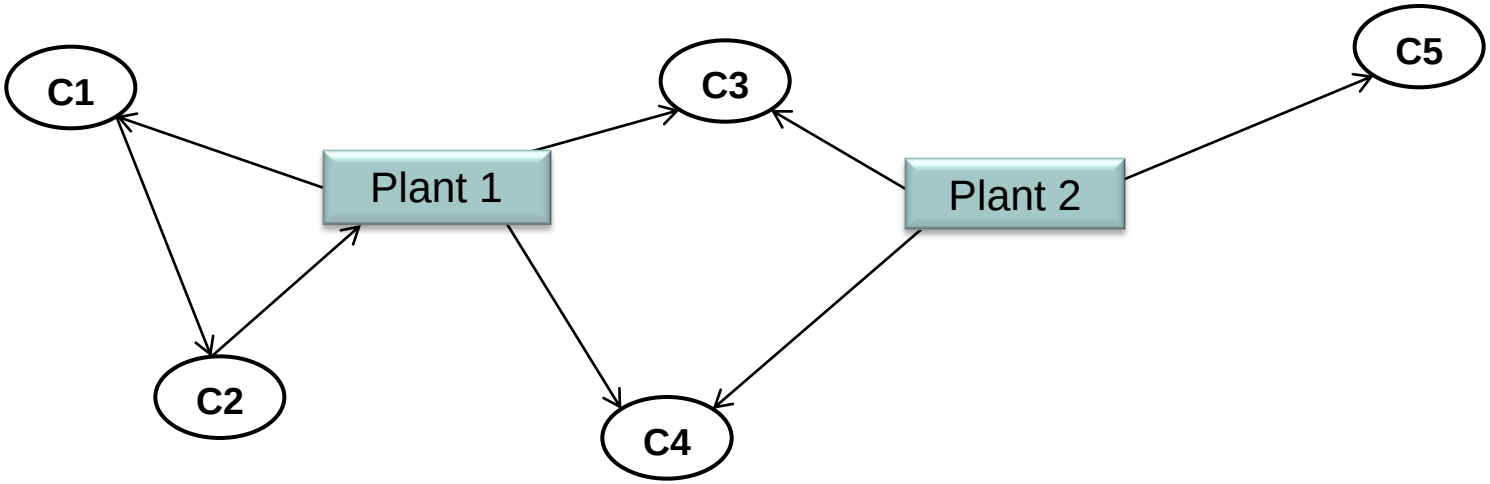
Center for Advanced Process Decision-making
Enterprise-Wide Optimization (EWO) Meeting – September 26-27, 2012

Background and Motivation

Industrial Gases Supply-Chain

- Multiple Plants and Depots (located or not at plants)
- Multiple Products *(LIN, LOX etc.)* and Product Grades
- Over-the-fence, call-in and distributed customers *(some shared customers)*
- Storage facilities at production sites and customer locations



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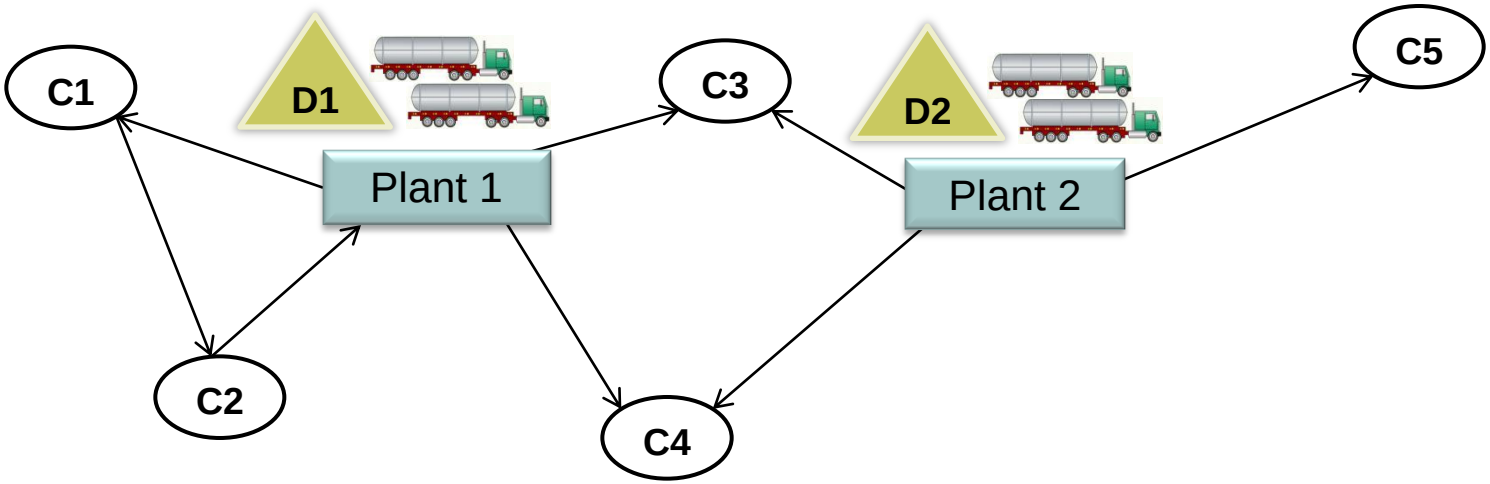

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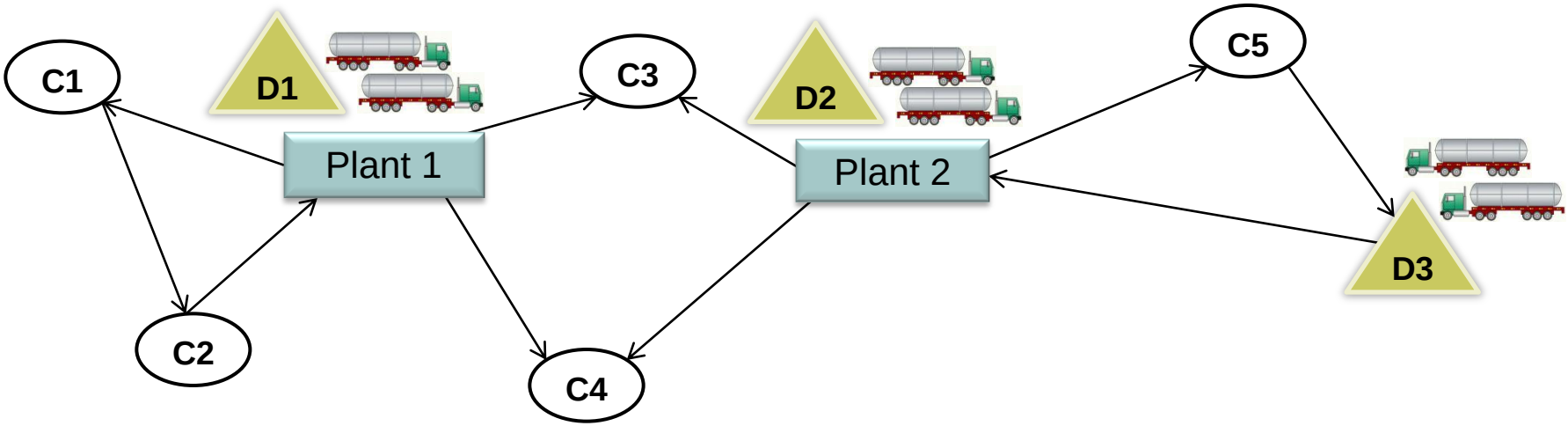

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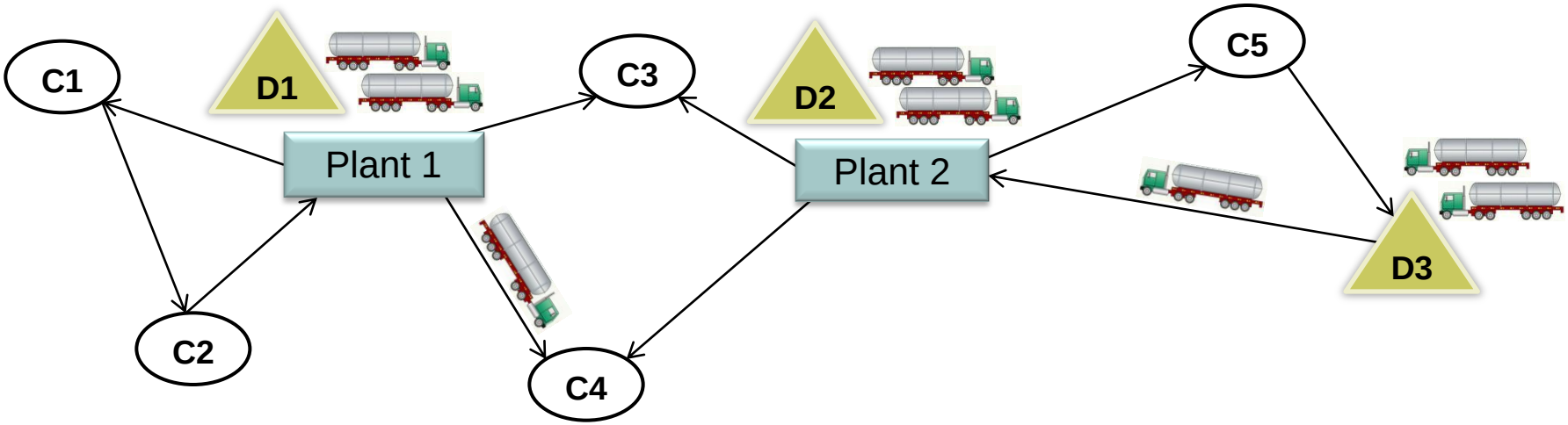

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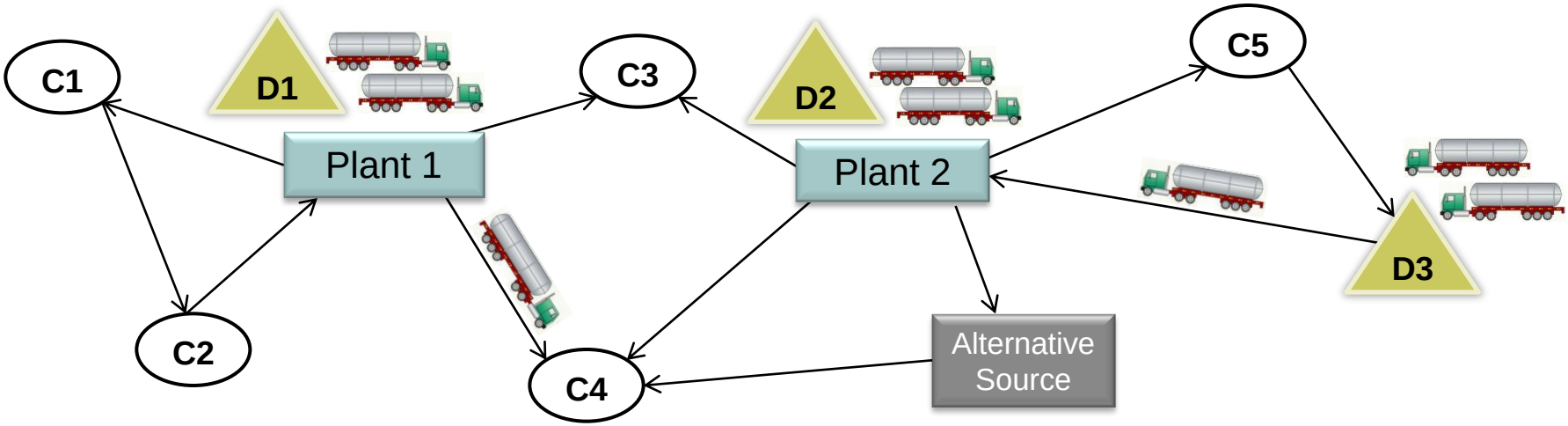

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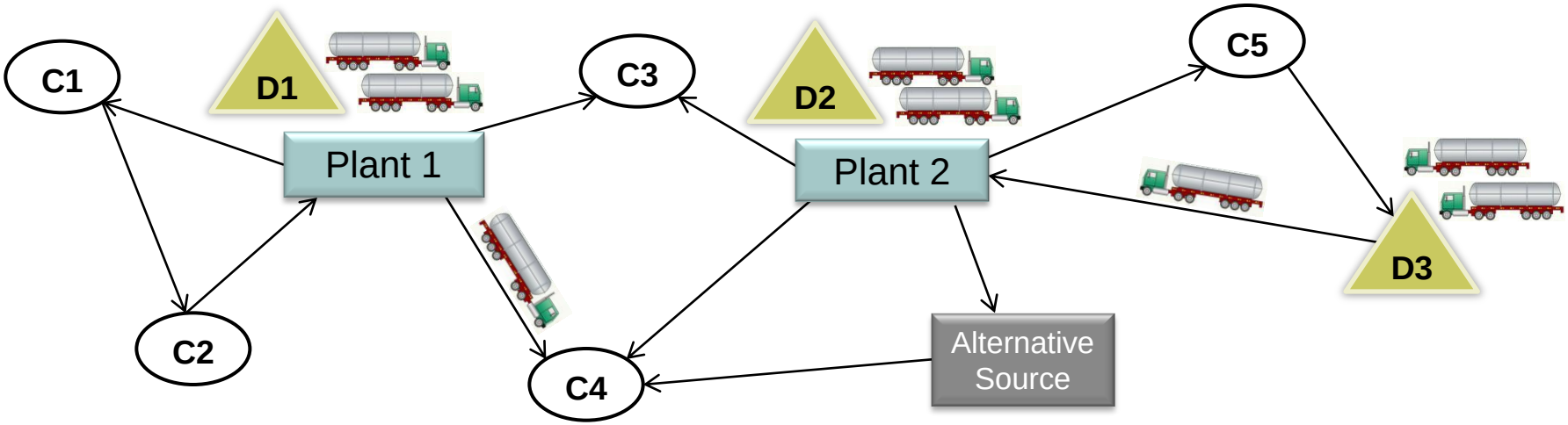

Goal

To quantify and access the savings associated with the ***Production-Distribution Coordination at Operational Level*** *using an approximate model*

Problem Statement and Main Assumptions

Given

- **Plants, Products, Operating Modes and Production Limits**
- **Daily Electricity Prices (off-peak and peak)**
- **Customers and their demand/consumption profiles**
- **Max/Min inventory at production sites and customer locations**
- **Alternative sources and product availabilities**
- **Depots, Truck availabilities and capacities, Distances**
- **Fixed Planning Horizon (usually 1-2 weeks)**

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Decisions in each time period t

- Modes and production rates at each plant
- Inventory level at customer location and plants
- How much product to be delivered to each customer through which route

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- Minimize total production and distribution cost over planning horizon

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Main Assumptions – Distribution Side

- Two time periods per day (peak and off-peak) are considered
- Trucks do not visit more than 4 customers in a single delivery

Mathematical Model (MILP)

Objective **Minimize total Production and Distribution Costs**

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Objective

Minimize total Production and Distribution Costs

Constraints on Production Side

Production Cost = Fixed Start-up cost
+ Variable production cost

- **Min/Max Production Capacity Constraints in each mode of operation**
- **Logic Constraints for switching between various modes of operation**
- **Max/Min Inventory limits at the production sites**
- **Plant Inventory Balance Constraints**
- **Demand satisfaction for pick-up customers**

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Constraints on Distribution Side

Distribution Cost = Cost of deliveries by trucks + purchases from competitors

- **Max/Min Inventory limits at the customer locations**
- **Customer Inventory Balance Constraints**
- **Truck Capacity constraints**
- **Material balance constraints for product pick-up and delivery points**
- **Max product purchase limit from competitor sources**

Large Industrial-Size Test Cases

Examples featuring:

- 2 to 5 plants with alternative modes of operation (hi LOX, hi LIN, etc.)
- 2 to 5 depots, 16+ trucks
- 2 or 3 alternative sources
- 2 products with different product grades (LIN, LOX)
- 14 time periods (peak and off-peak)
- 30 to 100 clusters (500+ customers)
- 150 to 1000+ routes proposed

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Input through Excel /GDX interface.

Additional Developments

Route Generation Algorithm

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Route Generation Algorithm

- Generates a set of routes to be used with the model, by inspecting all possible routes for given parameters:
  - Maximum route distance
  - Limited number of clusters visited (2 to 4)
  - Limited number of routes per plant (100 to 200+)

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- Excel interface

Generate Routes

Plant 1 - LIN

Route	Dist	Plant	Product	C1	C2	C3	C4
r1	0.918611	p1	i1	c1			
r2	50.47589	p1	i1	c7			
r3	65.21543	p1	i1	c31			
r4	66.12212	p1	i1	c1	c31		
r5	67.50362	p1	i1	c6			
r6	83.91647	p1	i1	c19			
r7	84.379	p1	i1	c1	c19		
r8	89.13239	p1	i1	c31	c7		
r9	90.74391	p1	i1	c16			
r10	91.08736	p1	i1	c18			
r11	91.18356	p1	i1	c1	c16		
r12	91.36757	p1	i1	c16	c19		
r13	91.49075	p1	i1	c1	c18		
r14	91.80722	p1	i1	c1	c16	c19	

Plant 1 - LOX

Route	Dist	Plant	Product
r600	65.21543	p1	i2
r601	67.50034	p1	i2
r602	90.74892	p1	i2
r603	153.6978	p1	i2
r604	155.3915	p1	i2
r605	173.1537	p1	i2
r606	194.4741	p1	i2
r607	195.4999	p1	i2
r608	222.9092	p1	i2
r609	236.2677	p1	i2
r610	240.4784	p1	i2
r611	254.8213	p1	i2
r612	256.922	p1	i2
r613	287.4294	p1	i2

Additional Developments

Ad Hoc Production Models

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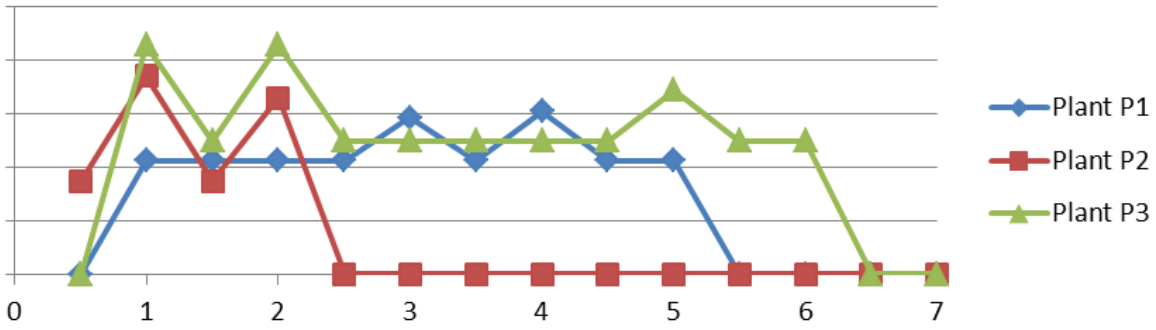
Ad Hoc Production Models

- Some plants have specific equipment configurations and production modes, which can not be represented in a general form.
- Production rates and power consumption for each mode can depend on:
  - Air flow
  - Outside temperature
  - Etc.
- Specific modes for over-the-fence gaseous customer demands can be considered.



Large Test Case

- 2 Plants, 3 products (LIN, LOX)
- 4 production modes for each plant
- 2 alternative sources
- 70 clusters (truck delivery)
- 14 time periods (peak and off-peak)
- 16 trucks (8 for LIN, 8 for LOX)
- Demands, min/max inventory, distances, electricity prices, etc.

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Model Size	Total proposed # of routes				
	Binary variables				
	Continuous variables				
	Constraints				
CPU results	Time Limit				
	Relative gap				

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Model Size	Total proposed # of routes	383	523	679	1,321
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	Binary variables	7,526	9,750	11,622	22,998
	Continuous variables	9,721	12,495	14,845	30,271
	Constraints	11,857	14,631	16,981	31,523
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Models implemented with GAMS

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Models implemented with GAMS / CPU results obtained with solver CPLEX 12.4

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Good quality solutions found in few CPU sec.!!!

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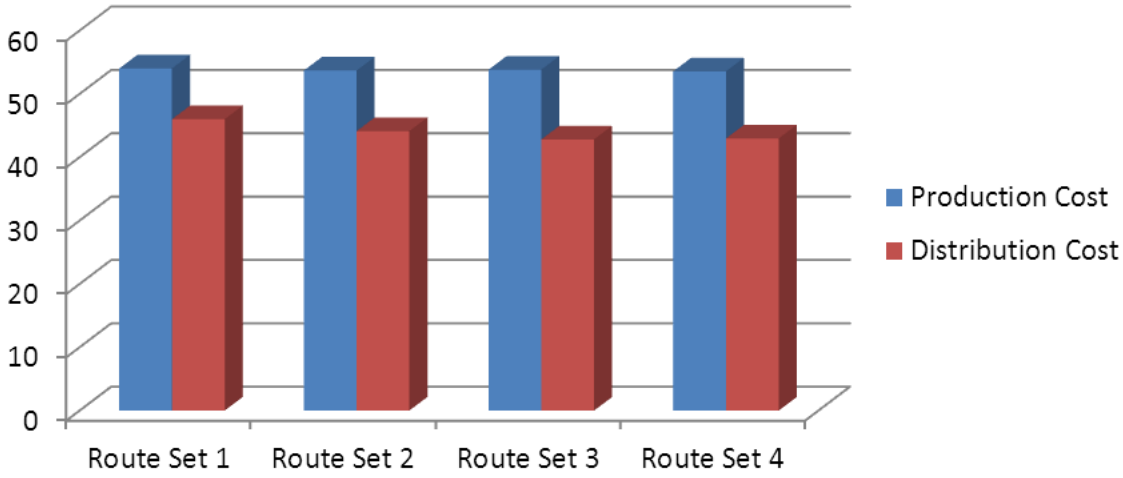
Large Test Case – Some Results



Decrease of Distribution Cost due to better routing options

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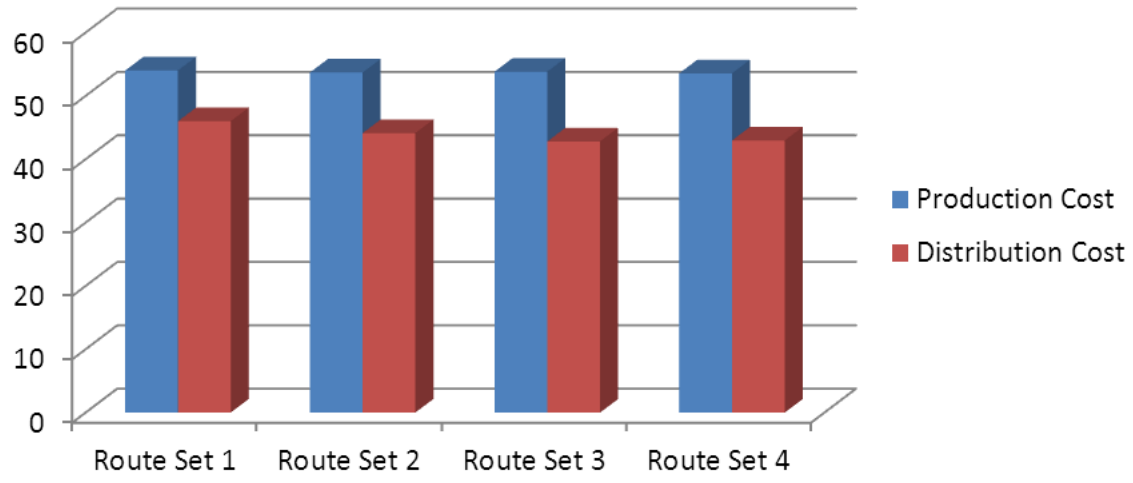

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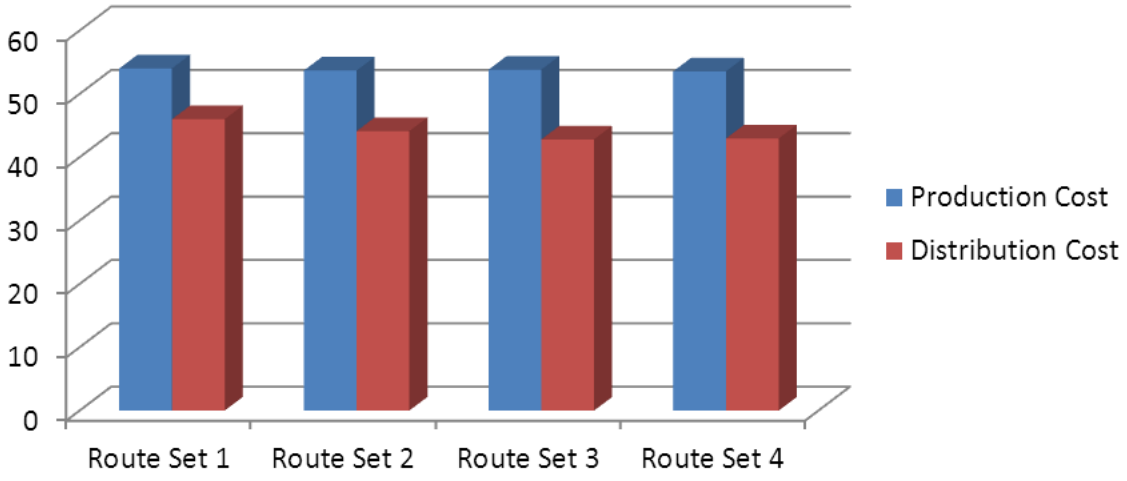

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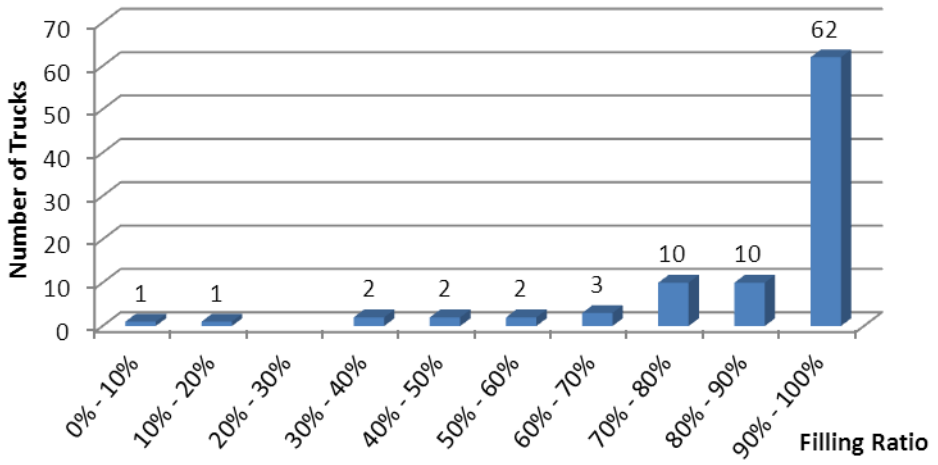
Solutions feature good/excellent filling ratios for trucks



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  - Multiple products, plants and depots
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  - Ad hoc production models
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Future work

- Improvements on clustering of customers.
- Stochastic model.